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Exploring factors and policies for poverty by agent-based simulation

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Abstract

This paper presents a case study on agent-based simulation concerning the growth of poverty. The aim is to support policy makers and researchers to explore different factors concerning specific localities and policies that affect poverty's nature and growth. The paper presents a rather inclusive model, incorporating characteristics about the local environment, the local economic structure, community institutions and demographic characteristics, together with characteristics of individuals populating the locality. Experimental results show the potential of the constructed model. We also discuss various visualization strategies that will support decision makers to better explore the complexity of the phenomenon and the effectiveness of foreseen policies.

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Keywords: agent-based; modeling; simulation; social phenomena; poverty; visualization

1. Introduction

As already pointed in [1], a social-artificial-natural system is far more than the sum of its parts. Thus, in simulating social phenomena we have to determine the different social, artificial, and natural parts of the system, and the way these parts interact at the micro level contributing to the development of local phenomena. Together, these local phenomena result to global changes and emergence of new ones at the macro level. The study of the effect of different combinations of social, technical, and natural characteristics of systems at various time scales are critical to understanding the effects of different factors/policies to the development (and emergence) of phenomena in complex systems.

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Multi-agent modeling techniques relying on the combination of economics, behavioral, and computer science have been extensively used to support decision making and policy making. Agent-based simulations allow the non-deterministic simulation of actors and their interactions under various circumstances. In this regard, as it is well known, agent-based simulation allows the study of phenomena occurring in complex systems. This is facilitated via the incorporation of well-understood and rigorously defined system characteristics, together with important features that cannot be defined and computed analytically: agents' behavioral tendencies, beliefs and goals, their social context, and the way this affects their perception of their decisions, shapes their opinion and further activities. Such features can be used to model a social-artificial-natural system at the appropriate level of detail, simulating the emergence of important phenomena at levels spanning from the local to the global.

This paper aims at presenting preliminary results towards understanding the effects of different social-technical-natural determinants to poverty. The aim is to build a generic and inclusive model for poverty that will allow policy makers and researchers to explore different local factors and policies that affect the nature and growth of poverty. Towards this, the paper presents a model for poverty growth which incorporates local characteristics (the local environment, the economic structure, the community institutions), characteristics of the specific individuals populating the environment (their work and wages, their educational level, their ambitions, their social network), as well as characteristics concerning demographics and their changes via immigration. The aim is to compute how poverty is being affected by specific policies for growth and sustainability. We also emphasize on and propose specific methods for the visualization of the simulation results, so as to better reveal the intricacies relating different determinants and of course the policies affecting them.

2. Related Work

There are many works concerning the agent-based simulation of complex social or biological systems [2, 3, 4, 5, 6, 7]. The technology and the experiences developed throughout these studies are important both to the development of multi-agent systems for simulating phenomena, as well as to delving into the complexity of the social phenomena studied. Our work has been certainly influenced by specific methodologies and tools proposed for the simulation of social phenomena [1, 2, 3]. However, as far as we know, there is not any study that aims at simulating poverty as an economic and social phenomenon at the appropriate level of detail so as to study the intertwined effects of different factors to the development of the phenomenon. There are studies that aim to provide specific theories and unify the global knowledge concerning the development of poverty, but these are rather theoretical studies [8, 9, 10]. Based on these studies, this work presents a computational model that can be used for studying the growth of poverty. As such, the model developed can be seen as (a) a rigorous realization of some theories concerning the development of poverty based on a comprehensive set of social-technical-natural factors, and (b) as a tool for testing the effects of (anti-)poverty policies foreseen in a specific locality, also in interaction with other localities.

As already said, we give special emphasis to the visualization of simulation results. Related work on this may be categorized as follows. First, there are standalone visualizations of various local characteristics [11, 12]. These are usually realized by flow charts or scatter plots. Second, there are multi-dimensional and linked-view visualizations concerning large spatiotemporal data sets, which may use plume graphs or cellular automata [13, 14]. However, existing methods present limitations to visualizing the way different determinants for poverty are intertwined and affect each other [15].

3. Poverty, policies, and local determinants

Poverty is typically a situation where a family income falls below some standard that varies by family size. This standard depends on the locality. Poverty can be measured in a relative or in an absolute manner: Relative poverty is based on the assumption that poverty depends on where a family stands in comparison to the others. In contrast, an absolute standard is based on the absolute position of a family. In this paper we consider a relative measure of poverty depending on the income of households with regard to the average income of the whole population.

Subsequently, we present the factors incorporated into the developed model and discuss their effects on poverty and potential policies that may affect them, according to [10]. The specification of the model is presented below.

Major *natural factors* that characterize a specific location with respect to poverty are *isolation*, *climate*, and *natural resources*. While isolation concerns the accessibility of the location to markets or population centers, climate may determine the attractiveness of a place for people and business. Natural resources may determine the types of businesses that might grow in a specific location. Isolation affects market exchange and trading, and it can also hinder the labor market. Fewer jobs limit skills and lower wages. Climate and the existence of natural resources are crucial determinants to the type of businesses that may grow in a locality. Thus, all these factors interact with the development of the economic structure. Policies may affect the attractiveness of a place by developing the necessary infrastructures, thus also affecting the economic structure.

The *economic structure* of a locality concerns the mix of job opportunities. This of course affects the *job demand* and determine the *skills* required, the *opportunities* for promotion, career development, and *income* growth. Migration is one way to adjust to economic opportunities. Limited job opportunities affect the skills and the educational ambitions of people who do not migrate, thus shaping the demography of localities [8]. In contrast, increased job opportunities require a greater variety of skills and people, affecting also their educational ambitions. Therefore, the industry-economic structure affects labor market skill levels and the level of poverty rates. People with ambitions to increase their income and acquire better education are likely to leave. However, those with limited income are less likely to invest in education, thus keeping skill levels low in the area. In-migration also affects the community and may affect the growth of employment, increasing attractiveness and creating new opportunities. It is very difficult to establish policies that alter an area's economic structure. Better education and encouraging mobility of young or relatively more advanced populations can raise incomes, but it will increase out-migration.

The role of *public* and *community institutions* becomes crucial, since they ensure the effective functioning of the community. They shape, monitor, and enforce rules about appropriate individual behavior, and reinforce social norms. Organization and order—through the functioning of public and community institutions—may attract businesses and people, affecting also the well-being of residents and providing alternative messages for better education, the creation of better opportunities, and ambitious targets. The design and implementation of any antipoverty policy requires a healthy, efficient, and effective public sector, and well-functioning community institutions.

In this work, according to [10], we consider a *social norm* to be a commonly observed behavior the development of which is based on past experiences (i.e., a learned behavior) and that is enforced by informal social sanctions. Thus, decisions concerning education, work, immigration, “well-being”, depend on social norms that are shaped by the social context of each individual, i.e., by the other individuals that the individual is *socially connected with*, as well as by the social economic structure. Norms also shape the functioning of institutions. Although policies may affect norms, in the context of this work we do not take these cases under consideration.

Demographics are linked to peer group effects, reinforce effects on behavior, signal differences in *economic* and *social expectations*, and shape future possibilities. Demographics correlate with behavioral issues and affect the usefulness of policies. In our case, demographics concern the types of households and families, as well as the social structure connecting individual units.

4. Modeling and Simulating the Growth of Poverty

Complex social simulations require methodological planning and developmental stages. Claudio Cioffi-Revilla proposes a viable methodology in [1] which we have adopted in this work. An important feature of this methodology is that one can start with a simple initial model and add complexity until a final model is constructed which satisfies specific requirements. Requirements concern the questions that the model can support answering. These, together with the basic entities, their relationships, and their dynamics, help specifying an initial model. One proceeds to refinements of the model by adding complexity and increasing the dynamics.

The basic research questions for our case study are the following. How do the different factors affect the growth of poverty? Can we predict whether specific policies address the issue? What are the effects of such policies?

For the specification of the multi-agent system realizing the model, we used the TROPOS methodology [13]. The system was finally built with the MASON platform [12]. MASON is suitable because it places no restriction on the design and the implementation of the multi-agent system.

Below we specify the various social, artificial and natural parts of the system, and the way these parts interact in the micro level contributing to the development of phenomena with regard to poverty.

Natural Environment: The natural environment is specified by factors representing isolation, climate, and wealth of natural resources. In our model these factors are represented by integer variables ranging in [*0*, *10*]. A value near *10* means better climate, less isolation (better accessibility), and more natural resources. Isolation includes the accessibility of the area, and the technological infrastructure facilitating it; actually, it is the mean value of the two variables representing these features.

When a policy against poverty is applied to a place, the natural environment may change with respect to the technological infrastructure and, thus, to the accessibility; in contrast, a negative policy could deteriorate accessibility.

Social System: The social system includes demographics, that is the social network connecting interacting individuals, public and community institutions, and social norms.

Demographics concern the types of households and families, as well as the social structure connecting individual units. Every agent simulates the basic functions of a real-person. An agent can search and get a job, make a family, immigrate and, of course, eventually die. Formation of minorities is also a characteristic of demographics. Demographics change dynamically based on and because of the behavior of the agents.

Each and every agent communicates with a specific number of other agents through the social network. The social network is a scale-free network which changes dynamically as new agents enter the locality or existing agents immigrate/die. The network is constructed by progressively adding nodes (agents) and by introducing links to existing nodes with a preferential attachment so that the probability of linking to a given node i is proportional to the number of existing links k_i that this node already has. Each link in the network is associated with a weight, with a value ranging in [*0.1*, *1*]. Weights are assigned to links randomly and affect the way agents interact and affect each other (this is further specified below).

Social Norms include the disposition of inhabitants to immigrate, their desire for education, their tendency to form minorities, and their perception of quality of life. For instance, the inherent disposition of the inhabitants to immigrate (an integer ranging in [*1*, *10*]) affects the tendency of others to whom they are socially connected. This tendency affects the agents' final decision to immigrate.

This tendency is calculated as follows:

$$tendency_i = (\sum_{i,j \in N} w_{ij} \cdot disposition\text{-}to\text{-}immigration_j) / |N| \qquad (1)$$

where N is an index of each agent in the system, and w_{ij} is the weight of a connection between agents i and j in the social network. Similar calculations determine all the other factors concerning the agents' overall behavior. Having said that, it must be pointed out that *all* decisions taken by the agents are non-deterministic; concerning immigration, even if one's tendency to immigrate is large, it may never make it to immigrate.

Skills are required by open positions and are possessed by agents. An agent must possess the required skills to fill a position. Skills are assigned randomly to agents, while the number and requirements of positions depend on the economic structure of the locality.

The desire for education concerns agents' desire/need to improve their skills, so as to get a better job, increase their income, and their quality of life. There is no specific threshold for the overall tendency of the inhabitants to immigrate and for their decision to be educated: The respective value for each agent is compared to the mean value of the whole community.

The tendency to the formation of minorities is represented by an integer. Lower values represent greater tendency.

The agents' perception of life quality is a real number ranging in [*1*, *10*]. This is calculated as the weighted sum of specific criteria concerning income, accessibility, climate, the functioning of the institutions, the quality of life perceived by other socially connected agents (also affected by the weight of their relations in the social network), and the formation of minorities. The weight vectors for computing the quality of life are randomly assigned to the agents and determine the special emphasis each agent gives to different factors concerning its own living.

As our aim is to study the effect that the overall behavior of institutions have in the agents' quality of life (via "organization and order"), and thus to poverty, we represent the overall functioning of the institutions by a single integer number ranging in [*1*, *10*]. A value near *10* means a better behavior. Policies may affect the functioning of the institutions.

Economic Structure: Social norms, the functioning of the institutions, and the different factors concerning the natural environment determine the development of economic activities and thus affect the opening of positions. The wage related to each position depends on the required skills. A policy applied to a region may affect the different factors concerning the natural environment and the functioning of the institutions resulting in more or, respectively, in less job opportunities. In addition, the relationships between the agents and the environment and between the agents and the institutions might affect the social norms and, consequently, the number of job opportunities may increase or decrease.

Typical Simulation Agent-Cycle: The agents are autonomous and heterogeneous (as far as their preferences and dispositions are concerned), interacting via their social connections with other agents. The goals of an agent are to avoid poverty (to keep the total income above the poverty threshold), and to keep the quality of life above the community's quality of life. To achieve these goals, agents search for job opportunities with better conditions, aim to upgrade their skills by being educated (so as to acquire skills and being promoted to better positions), and push for change in the policy of institutions (this happens by a "voting" scheme). If they fail to achieve these goals in their locality, then they increase their disposition to immigration.

When initiating the simulation the characteristics of the environment and the specification of the initial population and of the initial economic structure are specified. Then the demographic characteristics of the area are set either randomly or manually. The social network is constructed based on these demographic characteristics. Finally, when policies affecting the natural environment and the functioning of the institutions are implemented the natural environment, the economic structure, the demographics, and the social network are updated gradually.

5. Experimental results

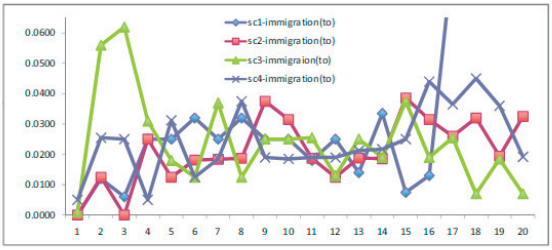
In this section we present and discuss results from four different scenarios concerning the effects of different policies and factors to the growth of poverty. Each scenario concerns a specific natural environment with a specific economic structure. While the characteristics of the natural environment vary in different scenarios (as far as the accessibility and technological developments are concerned), the same happens for the natural resources available - and thus the business activities determining the economic structure. Each scenario concerns a specific locality with a stable number of economic activities (seventy), each with a specific number of available positions (fifteen). Each position requires a particular type of skills and, depending on the type of skills required (from 1 to 9), each position is related to a specific wage. The numbers of positions per activity vary, depending on the skills required: 1/3 of the positions require low-level skills, while only 1 of the positions per economic activity requires high level skills. The business activities are categorized to "active" and "non-active"; during the span of the simulation, a specific economic activity may change status. Also, each scenario differs from the others in terms of the total population, the number of children, the functionality of the institutions, and of course in the policies applied (see Table 1).

Each scenario runs for 20 simulation cycles, each cycle representing a time span of one year. In the diagrams presented below we present average measures per simulation cycle for 10 different runs. For each scenario we show in Figure 1: (a) The changes in the population, (b) immigration to and immigration from the locality as a percentage of the population, (c) Changes in the percentage of unemployment and, of course, (d) The poverty rate (relative poverty), and (e) percentage of poverty for each of four different types of household (red line: "single", yellow line: "couple with children", blue line: "single with children", green line: "couple").

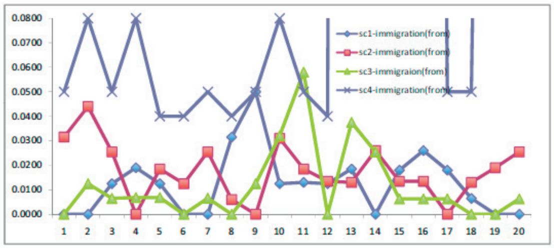
Concerning the reported results, one can see interesting (although expectable) conclusions. Regarding scenarios 1, 3, and 4, these concern quite similar settings: The accessibility and the technological development of the locality are quite high, although the economic structure is not that rich. The functionality of the institutions is also at a good level. However, in the first scenario there are positive policies with no restrictions to immigration, while in the 4th scenario there are negative policies with no restrictions to immigration. In the first scenario we can report a decrease in the poverty rate, which reaches a specific low plateau after year 10, while unemployment is decreasing year by year. Immigration to the locality is high in the last years of the simulation, while the immigration from the locality is at very low levels (there is some difference in the scaling of the diagrams for the Y axis). However, this is not the case for the 4th scenario, where the poverty rate increases until year 10 and then starts to descent fast. This is due to large immigration percentages from the locality, in combination with very low immigration to the locality (resulting also to a decrease of the total population). Unemployment after year 10 decreases significantly, which is expectable given that the "active" population immigrates. Things are different for the 3rd scenario where agents do not immigrate, although negative policies apply: The poverty increases and reaches a high plateau at year 10 (then, it decreases at a low pace) and unemployment reaches very high levels. Also the poverty percentage per different types of households is very high. Finally, the 2nd scenario shows a very nice case for a developed region where positive policies are applied (although institutions do not function as wished).

Table 1. The specific characteristics of the different scenarios

Factors	1st Scenario	2nd Scenario	3rd Scenario	4th Scenario
Accessibility	8	7	8	8
Tech. Development	8	6	8	8
Active Businesses	25	49	27	30
Non-Active Businesses	45	21	43	40
Population	1800	1800	1860	1800
Children	300	300	360	300
Funct. Of Institutions	7	5	8	7
Policies:	P-N-IR	P-W-IR	N-W-IR	N-N-IR



a)



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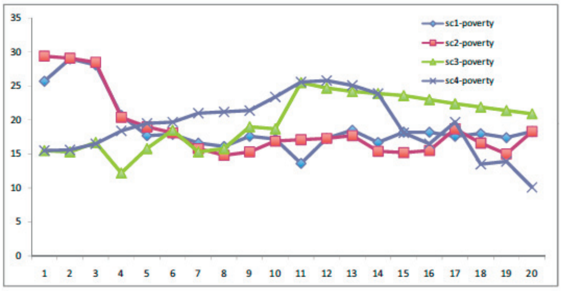
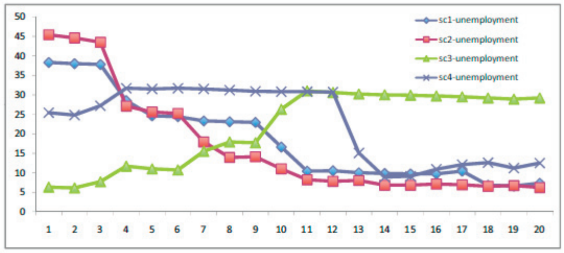
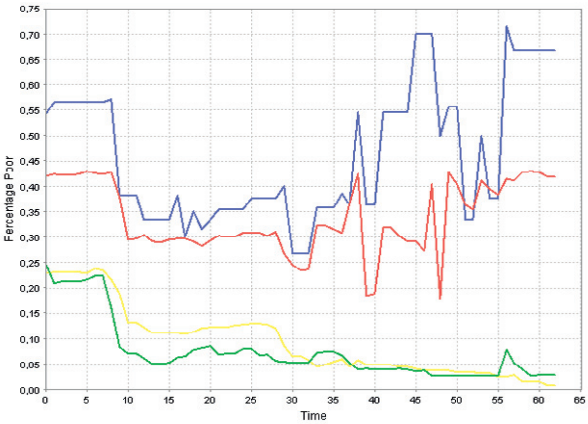


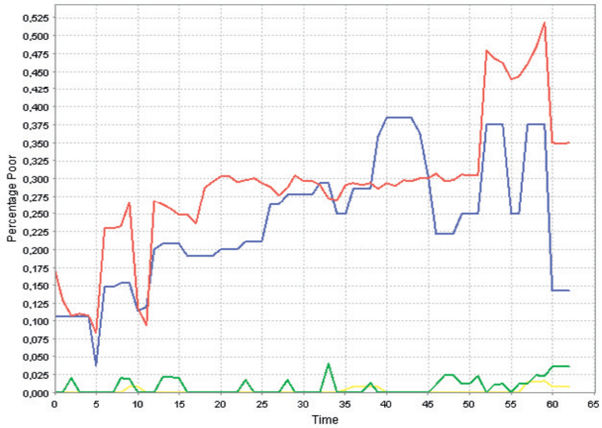
c)



d)



e)



f)

Fig. 1. Simulation results for the different scenarios (sc-X): a) Immigration(to) b) Immigration(from) c) Poverty rate d) Unemployment e) Household poverty, sc-1 f) Household poverty, sc-3, for both e) and f) the colors are as follows: (red line: “single”, yellow line: “couple with children”, blue line: “single with children”, green line: “couple”)

The above reported indicative results show (a) the viability of the model, (b) interesting results for cases simulating real-world situations, (c) the sensitivity of the model to different settings and parameter values. Adding more features to the model and being able to get more fine-grained results we may further delve into the intricacies of poverty growth.

6. Visualizing social simulation results

As described in [15], visualizing social phenomena simulation results using any of the existing methods presents challenges. We need to visualize various local characteristics that are of different types. In particular, immigration is spatiotemporal, while poverty and unemployment are temporal. Indeed, there is a mismatch in the qualities that each method visualizes; thus, to address this mismatch we adopt a multiple view approach: We use a parallel coordinate visualization for the local environment, the economic structure, the community institutions and the overall change in demographic characteristics (see Fig. 2). To visualize the temporal evolution of demographic characteristics we use "bubble charts" (see Fig. 3) which, apart from demonstrating the continuity of the simulation, also imply a size relative to the social network. The multiple view approach facilitates the interpretation of the results, and correctly accommodates various types of data, showing also the effect of one to the other; in the meanwhile, it allows the addition of further domain-specific views (e.g., a geographic view, a timeline, etc.) [19]. Moreover, the use of parallel coordinates has a number of advantages. Indeed, no other visualization method can plot all local characteristics at a time. One can have a very fast overview of the results, and a quite accurate one too [19]. In our case, one can visualize a big number of scenarios and draw useful conclusions from the visualization. It is immediately visible that when a positive policy is applied, the percentage of poverty, the percentage of unemployment, and immigration-out remain low. In contrast, when no policy is applied, either high percentages of poverty and unemployment, or high immigration is present.

In addition, one can filter the results by highlighting suitable regions in one or more coordinates. Filtering is very efficient in the case when the coordinates are placed in a logical order [19]. In our case, a logical order would be to treat the social-artificial-natural factors implemented in the model as if they were input to a visualization system and poverty, immigration, and unemployment as outputs of this system. For example, in Fig. 2 we can see highlighted the scenarios when a policy has been applied (red lines). Scenarios when no policy is applied are faded out on the visualization. Since local characteristics are ordered before demographic results, we understand that highlighting regions of the left part limit the results we observe. While the multiple view seems to apply on other social phenomena simulation results, one should in general be aware of sorting and scaling issues. In our case for poverty, it seems that such issues are avoided at large, since the order of the coordinates is not arbitrary and a common scale for all demographics does not seem to be applicable. However, what other scaling options might be useful remains so far an open question.

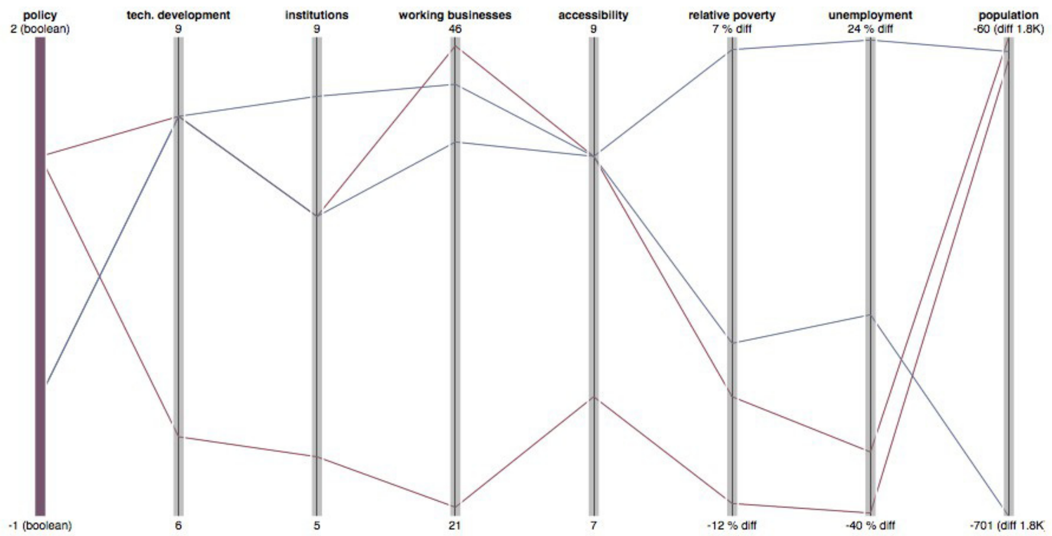


Fig. 2. Parallel coordinates visualization filtered to show scenarios when policies are applied (red lines): poverty, unemployment, and immigration seem to remain low regardless the initial development status of the environment.

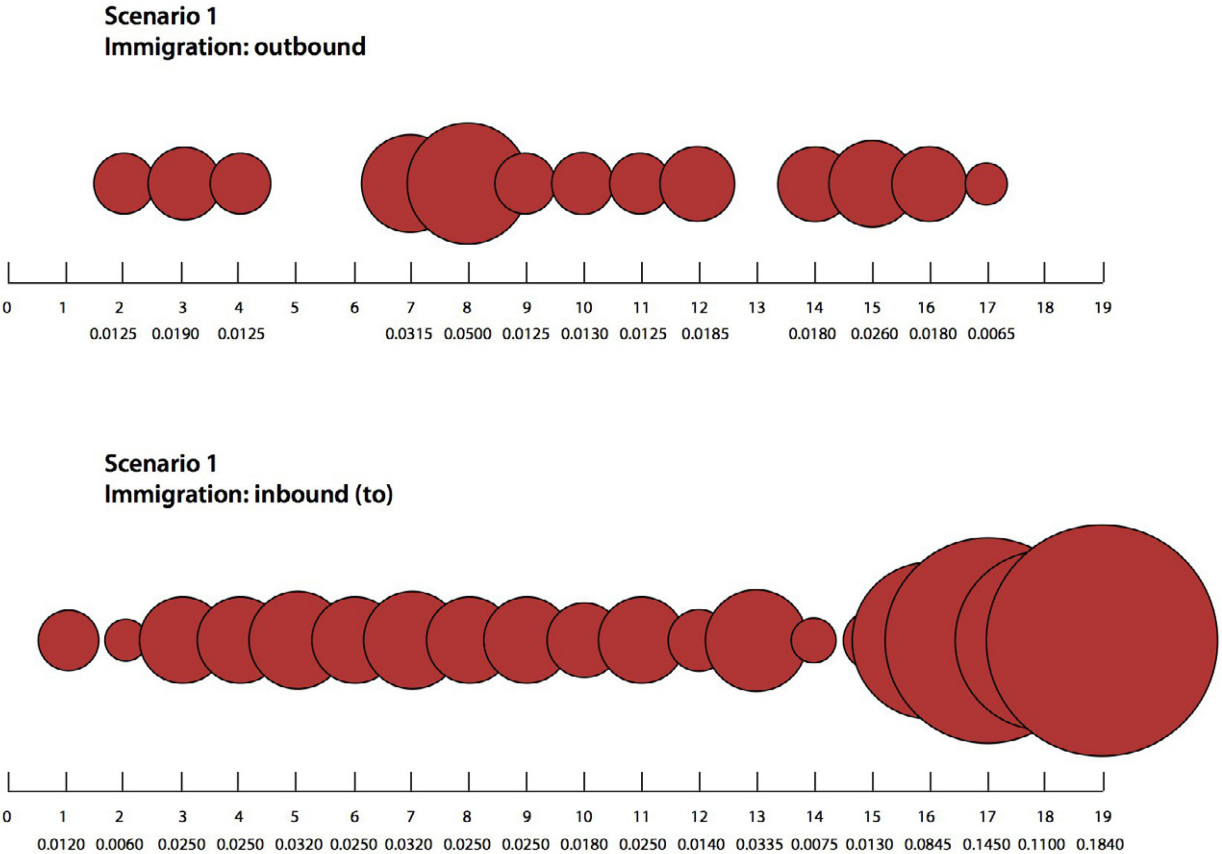


Fig. 3. Bubble chart presenting the evolution of immigration over time (over the 20 simulation cycles, from cycle 0 to 19).

7. Conclusions

Poverty is an emerging and emergent phenomenon occurring in many localities of many countries. This work aims at proposing agent-based simulation as a tool towards understanding the factors affecting its growth and nature, test the success of policies, or understand their failure to fight poverty. We have built an inclusive model and showed its potential, together with the appropriate visualization techniques to serve these purposes.

Our future work plans include improvements in various directions. At the moment, policy changes do not affect social norms when scenarios run, however it it realistic to consider such a possibility. Moreover, we will conduct additional experiments with a greater variety of scenarios in order to facilitate comparisons with real-world data to provide a better validation of the model itself. Concerning visualization of the results, we aim to combine the methods described above with real-world data visualization, in order to provide an intelligent user interface which would allow decision makers better grasp the influence of various policies and compare them to simulated scenarios with similar parameters.

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